FINAL SURVEY REPORT:

ERGONOMICS INTERVENTIONS

FOR SHIP RECYCLING AND REPAIR PROCESSES

at

PUGET SOUND NAVAL SHIPYARD,
Bremerton, Washington

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SURVEY DATE: October 20 - 21, 1999

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ABSTRACT

A pre-intervention quantitative risk factor analysis was performed at various shops and locations within Puget Sound Naval Shipyard, a public shipyard that provides ship repair and ship dismantling services for the U.S. Navy. Five specific job tasks were identified for ergonomic analysis. These tasks include: the drydock sorting pad operation, the removal of insulation from vessels, the manual materials handling task in the "cut and carry" process, the use of reciprocating saws to separate components and hulls, and the removal of terrazzo tile with a chipping hammer. Possible engineering interventions to address the risk factors for each task were suggested. Final outcomes are reported in this report.

I. INTRODUCTION

IA. BACKGROUND FOR CONTROL TECHNOLOGY STUDIES

The National Institute for Occupational Safety and Health (NIOSH) is the primary Federal agency in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. Since 1976, NIOSH has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures. Initially, a series of walk-through surveys are conducted to select plants or processes with effective and potentially transferable control technology concepts or techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities will build a database of publicly available information on hazard control techniques for use by safety and health professionals who are responsible for preventing occupational illness and injury.

IB. BACKGROUND FOR THIS STUDY

The background for this study is reported in “Preliminary Survey Report: Pre-Intervention Quantitative Risk Factor Analysis for Ship Recycling and Repair Processes at Puget Sound Naval Shipyard, Bremerton, Washington,” Report No. EPHB 229-17a by Hudock and Wurzelbacher, 2000 and in “Interim Survey Report: Recommendations for Ergonomics Interventions for Ship Recycling and Repair Processes at Puget Sound Naval Shipyard, Bremerton, Washington,” Report No. EPHB 229-17b by Hudock and Wurzelbacher, 2001. Both of these reports are available on the NIOSH website: http://www.cdc.gov/niosh/ergship/reports.html.

IC. BACKGROUND FOR THIS SURVEY

The Puget Sound Naval Shipyard (PSNS) was selected for a number of reasons. Puget Sound Naval Shipyard is a public shipyard in the Pacific Northwest, which performs both ship repair and ship recycling on large military vessels. The shipyard has both a developing ergonomics program and a process improvement program that has addressed ergonomic concerns within the yard.

II. PLANT AND PROCESS DESCRIPTION

IIA. PLANT DESCRIPTION

Plant Description: Puget Sound Naval Shipyard is located adjacent to the city of Bremerton, Washington, one hour west of Seattle by ferry, and approximately 30 miles north of Tacoma. The shipyard proper encompasses 344 acres of land. The shipyard facilities include approximately 400 separate buildings, nine permanent piers including 12,310 feet of deep water space, and six drydocks. This shipyard is one of the largest industrial installations in the State of Washington.

Corporate Ties: U.S. Navy Sea Systems Command

Products: Puget Sound Naval Shipyard performs overhauls and repairs of all sizes and types of U.S. Navy ships as well as being the home port for six active ships. Approximately 41 % of the workload of the shipyard involves the inactivation, reactor compartment disposal, and recycling (IRR) of nuclear-powered submarines and surface vessels. Approximately 12 surface vessels and 88 submarines have been recycled in the past 12 years.

Age of Plant: Puget Sound Naval Shipyard was established in 1891 as a U.S. Naval Station. Most facilities are less than twenty years old.

Number of Employees, etc: Approximately 8,200 civilian employees, of which 3,500 are production workers. Average age of production workers is approximately 42 years of age.

IIB. PROCESS DESCRIPTION

IIB1. Bin Emptying at Drydock Sorting Pad Process

As the surface vessels and submarines are being dismantled as part of the Inactivation, Reactor Compartment Disposal, and Recycling activity, hundreds of bins of scrap metal are generated. Each bin measures approximately 5 feet by 3 feet by 3 feet. The bins hold a variety of material: stainless steel, painted steel, unpainted steel, aluminum, and other metal components. Each bin is filled during the “cut and carry” dismantling process for each vessel within the drydock. The scrap bins are moved from the vessels to the sorting pad area by forklifts. The sorting pad is surrounded by large shipping containers (approximately 5 feet x 20 feet), each for a specific type of metal.

The sorting pad worker removes the individual pieces of metal from the scrap bin by hand. The worker makes a determination of the type of metal in hand and then carries the item to the appropriate shipping container. The worker then places or throws the item into the shipping container and returns to the scrap bin for the next item. Each bin takes approximately 20 minutes to empty and sort. Individual items can weigh anywhere from a few ounces for metal strapping to in excess of fifty pounds for triple valve assemblies.

The sorting pad worker often reaches far across or deep into the bin while grasping objects of unknown weight. Awkward postures of the back and neck, such as extreme lumbar flexion and neck extension, are fairly common. Strain of the shoulder, neck, and back are possible due to the manual lifting tasks. Some items are relatively heavy resulting in increased physiological strain on the worker.

IIB2. Insulation Removal on Surface Ship in Drydock

Insulation from the bulkheads and ceilings of vessels being dismantled is removed by insulators. The workers first cordon off the immediate work area to discourage entry by unauthorized personnel. This action is done by hanging warning tape and placards (e.g., "WARNING Man-Made Vitreous Fibers") around the work area. The insulators don totally encapsulating chemical protective suits and supplied-air hoods under positive pressure. The initial task of the worker is to remove the insulation tie caps. These small, round disks secure the insulation onto the metal insulation studs. These disks are removed using pry bars or wrecking bars of various sizes while standing on ladders to reach the overhead insulation. Once all the insulation tie caps have been removed, the worker uses a hawksbill knife (i.e., a knife with a short, downward-curved blade) to cut the insulation into manageable widths of approximately 18 inches. While cutting into the insulation, a co-worker sprays the surrounding air with a water mist to entrap any loose fibers that may otherwise be respirable.

The worker then pulls the insulation to free it from the bulkhead or overhead area. The insulation is bagged and disposed of properly.

The vast majority of work for the insulation removal workers is performed with arms overhead or out in front and away from the body, either using pry bars or knives, straining the arms, shoulders, and neck. Often the worker is on a ladder and is leaning backward (back extension) to get to the work as opposed to repositioning the ladder. Back extension such as this can be stressful to the worker. Pulling the insulation off the bulkheads or overhead areas requires the use of force to separate the insulation from the surface areas. This task is stressful to the arms, shoulders, neck and back.

IIB3. Reciprocating Saw Operations in Ship Dismantling

Ship dismantling requires the separation of components, bulkheads, and hull sections from adjoining locations. This separation is accomplished either by torch cutting or by using a reciprocating saw to cut through the steel, aluminum or other material. Torch cutting requires a fire-watch crew to stand by and a certain level of expertise by the user. Cutting with a reciprocating saw does not require the fire-watch crew and can be accomplished by nearly every worker, making it the preferred method among supervisors. Also, areas containing suspected hazardous materials must be mechanically cut to minimize worker exposure to the substance. Chemical protective clothing is worn when there is the possibility of exposure to known hazards. Mechanical cutting can take place overhead to remove wire hangers, between shoulder and floor height to remove bulkheads, or below floor level to remove decking and supports. Some components are lowered to the deck to be cut to reduce the amount of overhead work.

Workers assume a variety of postures to cut the pieces of metal including kneeling, sitting, lying down, bending over, standing on ladders, etc. Workers typically cut for 2-3 hours and then carry cut material to a disposal area for another 2 hours. Workers often work in pairs, switching between cutting the material with the eight pound reciprocating saw and supporting the item being cut. Heavier items are removed using tandem lifts.

The ergonomic risk factors for reciprocating saw operators include: awkward postures of the spine and wrist, static kneeling postures, forceful exertion of the upper extremity to hold the reciprocating saw, and high noise exposure. Particularly significant is the exposure to hand-arm or segmental vibration from using the powered reciprocating saw. (Vibration damping gloves are required personal protective equipment while using the saw). Normal operation of the saw results in vibration that has been reduced by an anti-vibration mechanism incorporated into the design of the saw. However, when initiating a cut (plunge cutting) or when the blade binds in the material, an extreme amount of vibration is transferred to the arm of the user. The manual material handling of the cut pieces may result in back, neck or shoulder strain of the workers.

IIB4. Removal of Terrazzo Tile with Chipping Hammer

During the outfitting of vessels, some of the decking surfaces are covered in tile. This is particularly true of mess hall and lavatory facilities. Before the deck plate can be cut by either torch or reciprocating saw, a path must be cleared of tile. The tile is removed by using a chipping hammer to flake the tile off the deck surface. This task requires the worker to kneel, sit or bend over the deck surface to operate the chipping hammer.

Chipping tile from deck surfaces puts the worker in awkward postures, having to kneel or sit on the deck. The back and neck are often flexed. Exposure to hand-arm or segmental vibration is due to having to hold the chipping blade in place with one hand while holding the tool weight and operating the trigger with the other hand. Few improvements to these tools have been made since the 1900's. Noise exposure is also very high with the use of chipping hammers.

IIB5. Manual Material Handling in the "Cut and Carry" Process within IRR

As part of the Inactivation, Reactor Compartment Disposal, and Recycling process at PSNS, material is cut apart and stored at temporary locations within the vessel being dismantled. This material is then manually moved from the internal storage areas to scrap bins for removal from the ship by crane. Depending on how the material was cut, it may require more than one individual to safely lift the object and carry it to the scrap bin. Somewhat confined spaces and the clutter of the stored material create tripping hazards in the narrow passageways.

The manual material handling of scrap metal may result in strains of the lower back, neck, shoulder and upper extremities. Tripping hazards may be present. Sharp edges on the cut metal may cause lacerations to ungloved hands.

III. CONTROL TECHNOLOGY

IIIA. BIN EMPTYING BY SORTING PAD WORKER INTERVENTION

Changes in how the scrap bins are presented to the worker may help in eliminating the extreme back flexion required to reach to the bottom of the bins to remove items. Tilting pallet jacks can be used to tilt the scrap bin once some of the material has been distributed to the shipping containers. Ultimately, the accurate sorting of material into separate scrap bins at the vessel would eliminate the need for the sorting pad.

IIIA1. Bin Emptying Intervention Selection

After much consideration and research into the commercial materials handling products available for this type of operation, a tilting table was chosen. A forklift is used to load the self-dumping hoppers onto the tilting table, at which point they are slowly and incrementally tilted to a maximum of 30 degrees. This allows the discharge chute to function as a horizontal work surface, at a height of approximately 30.5 inches. By limiting vertical rotation to 30 degrees, the material in the hopper will not inadvertently fall out onto the operator's feet.

No commercially available, off-the-shelf products with the required specifications existed on the market. Only one vendor was found that was willing to modify an existing platform, with a capacity greater than the estimated 5700 pounds, according to the shipyards specifications. Vestil Manufacturing Company (Angola, Indiana) supplied a modified table as a test model for the project. This table included a 30-degree tilt mechanism, was pneumatically powered, with a guarded remote foot pedal control, and was welded to the raised segregation platform at the bottom of the drydock.

IIIA2. Laboratory Evaluation of Tilting Table

NIOSH conducted an instrumented biomechanical evaluation of the tilting table. This evaluation was carried out, in the laboratory, utilizing the Peak Motion capture system and Jack Biomechanical Analysis Software.

Video footage of the scrap metal sorting task was used to construct a laboratory experiment to compare the biomechanical loads of the sorting task without the tilting table, and with the tilting table in place. This experiment utilized a framed wooden mock-up of the self-dumping hopper. The analysis of this experiment was constrained to a worst-case scenario, namely, the removal of a heavy object, from near the bottom of the bin.

During on-site evaluation, several heavy objects were weighed. Valves and flanges from high-pressure steam lines, a common type of scrap, weigh approximately sixty pounds, and one object weighed 120 pounds. According to the workers, such objects weighing in excess of 100 pounds are common, and have been encountered many times in a single day.

The mock-up of the tilting table was first placed flat on the floor, and multiple trials were run using the Peak Motion Capture system. Each trial consisted of about three to four seconds of motion, as the subject stepped up to the front of the hopper, bent forward, reached in and picked up an object from near the bottom of the bin, and then turned to take the object to the nearby shipping containers.

A single frame of video was chosen from each trial for biomechanical analysis. This frame corresponded to the lift-off point of each bend-lift-carry sequence. That is the point at which the object is no longer being supported by the bin, and is fully supported by the human.

The second phase of the experiment involved the same process, but this time with the mock-up elevated and tilted forward to the same position, as it would be if mounted on the tilting table, and moved to the maximum inclination of 30 degrees. Again multiple trials were conducted, using a single frame corresponding to the lift-off point.

Jack®, a three-dimensional human modeling and biomechanical analysis software developed at the University of Pennsylvania, was used to evaluate the biomechanical loads associated with this sorting task. A 50 lb. load was used for all of the calculations. The results from the pre- and post-intervention trials were then compared.

IIIA3. Biomechanical Analysis of Lifting Postures

With the analysis tools available in the Jack® software we were able to compare several measures of biomechanical stress. The Low Back Analysis tool gave measurements for spinal disc compression, anterior/posterior shear, lateral shear, and muscle tension of several major muscle groups of the torso region. The disc compression and shear measurements were calculated for the L4/L5 joint in the lower spine. The static strength calculations use a method similar to the University of Michigan 3D Static Strength Prediction (3DSSP) protocol. This tool gave results for the percentage of the population that would have the strength capability to do this task, partitioned into categories based on the major body joints (torso, hip, knee and shoulder).

Again, using the Jack® biomechanical analysis software, an evaluation of the lifting tasks according to the NIOSH lifting equation protocol was completed. The analysis gave a value for the Recommended Weight Limit (RWL), the weight of the load, for a specific set of task conditions, that nearly all healthy workers could perform over a substantial period of time without an increased risk of developing lifting-related lower back pain (Waters et al, 1994). The program also gave a value for the Lifting Index (LI), which is a relative estimate of the level of physical stress associated with the given manual lifting task. It is likely that lifting tasks with a LI > 1 pose an increased risk for lifting-related low back pain for some fraction of the workforce. At an LI > 3, many workers will be at an elevated risk of lower back pain (Waters et al, 1993).

Below are tables summarizing the results of the ergonomic analysis using Jack®.

Table 1. Tilting Table Low Back Analysis

Measure (50 lb hand load)	**Pre-Intervention**	**Post-Intervention**	**Percent Load Reduction**
L4 / L5 Disc Compression	4275 N	1984 N	54 %
Anterior / Posterior Shear	~ 1000 N	~ 400 N	~ 60 %
Erector Spinae Muscle Tension	> 2000 N	~ 950 N	~ 52 %

Table 2. Static Strength Prediction

Measure (Male % Capability)	**Pre-Intervention**	**Post-Intervention**	**Increase**	**Percent Improvement**
Torso	60	95	35	58 %
Hip	50	90	40	80 %
Knee	50	100	50	100 %
Shoulder	85	100	15	18 %

Table 3. NIOSH Lifting Equation

Measure	Pre-Intervention	Post-Intervention
Lifting Index (LI)	3.90	1.23
Recommended Weight Limit (RWL)	12.79	40.56

The results of this analysis show that the tilting table is an improvement over the old system, of a roto-bin set upright at ground level. Comparison of the biomechanical loads before using the tilting table and afterwards shows that the loads placed on the worker doing this task are significantly reduced.

IIIA4. Field Testing of Tilting Table

The test table was installed in the drydock sorting area and was in use for several months. The tilting table received favorable reviews from the segregation slab workers. The sorting area workers generally liked the tilting table, since it made the sorting task less strenuous by reducing the amount of bending, and the overall effort required to segregate a hopper of scrap material. The shipyard felt that the pace of the task was not significantly changed by the use of the tilting table. The workers also mentioned a few problems with the table, and suggested modifications to increase the device's usefulness and durability. Suggestions included:

1. Tilt table platform was not large enough to easily accommodate the roto-bins. The loading platform needs to be larger to allow more space within which to place a full roto-bin. This makes the task of the forklift driver easier.

2. Construction of tilt table was not heavy enough to be durable over long-term use. It should be made of heavier gauge material to reduce flexure and increase durability, in the interest of reduced repairs.

3. The tilt table needed to be more mobile, or there needed to be more units to allow for more than one roto-bin at a time on the sort-slab. Instead of being rigidly welded to the sort slab, it should be mounted on a heavy platform that could be easily moved by a forklift.

IIIA5. Followup on Tilting Table Intervention

Based on the results of the laboratory experiment, and worker reaction to the experimental tilting table, more such tables have been purchased. The new tables are improved over the original test table in several ways. They are made of heavier material so as to be more durable. The loading platform is larger to allow easier loading of the roto-bins onto the table. The exterior of the tilt table around the edges of the loading platform are enclosed in an expandable skirt to minimize pinch point hazards. The new tables will also be made mobile by mounting them on a large ballast plate that can be moved by forklift. These mounting plates will be made of 1.5-2" steel. The shipyard has purchased two more tilting tables for $4025 each plus the cost of installation, and construction of mounting plates that will be carried out by the shipyard.

IIIB. INSULATION REMOVAL POSSIBLE INTERVENTIONS

Shipyard personnel reported that often elevated work platforms are erected to raise the insulation removal worker. However, at times, the space constraints inherent to submarines and surface vessels preclude the use of the platforms. At PSNS, the worker accomplishing the insulation removal task decides if, or when, to use an elevated platform. Since platform use is not a standard work practice at PSNS, ergonomics awareness training to all shipyard workers may allow them to make better-informed decisions on elevated platform use for insulation removal.

IIIC. POSSIBLE INTERVENTIONS FOR THE RECIPROCATING SAW OPERATIONS IN THE IRR PROCESS

Puget Sound Naval Shipyard has developed and offered a safety and ergonomics course for reciprocating saw operators. The shipyard has started to purchase pneumatic reciprocating saws that have a vibration rating of 8.75 m/s^2, which is about 25% lower than that of the current electric reciprocating saws in use at the yard.

If saws are utilized, the use of wheeled tripods or standing jigs as already developed at Puget Sound Naval Shipyard, will remove the worker from the vibration exposure. The addition of a stabilizing handle near the front of the tool that isolates some of the vibration from the worker is also a promising idea. Modifying the saw trigger mechanism to work from palm pressure as opposed to finger pressure was also done at Puget Sound Naval Shipyard to minimize trigger finger complaints. Shipyard personnel noted that while tripods and stands are available to support the reciprocating saws, the present supports have not been widely accepted by the workforce due to their being cumbersome and of limited application.

IIID. TILE CHIPPING POSSIBLE INTERVENTIONS

Removing tile from deck surfaces requires the worker to kneel or sit on the deck. Providing kneepads or cushions minimizes some of the contact stresses. Low industrial seating wheeled stools are available for approximately $150 each. Depending on the application, worker postures may benefit from using the stools.

If chipping hammers can not be replaced as the tool of choice for this task, it is recommended that the widest blade possible (at least 2 inches) be used to minimize exposure time and the most vibration-damped tool available be used. New chipping hammers range in price from $400 to $750. No known action was taken for the tile chipping intervention.

IIIE. MANUAL MATERIAL HANDLING IN “CUT AND CARRY” OPERATION POSSIBLE INTERVENTIONS

Ship dismantling requires that most internal components be removed from the vessel before the vessel is cut to pieces. The removal of components through ship passageways to staging areas is currently performed by manual material handling. The possibility was considered that flexible conveyor systems or cable pulley systems can be used to either move material to the staging area or to move material into the scrap bins in the staging areas. Portable hoists may also be useful in the staging areas as well to move heavy or bulky material. However, the shipyard responded that a major constraint was the limited deck space. Several conveyor types had been tried with limited success. During the trials, there were difficulties in starting and stopping the conveyors at desired locations, parts would hang up in the narrow passageways and maintaining good control of the flow of material off the conveyor.

IIIF. OTHER ERGONOMIC PROJECTS AT PSNS

Lean Manufacturing – As with many other shipyards, Puget Sound Naval Shipyard is investigating lean manufacturing principles and their application to the ship building or ship repair workplace. The shipyard joined a National Shipbuilding Research Program pilot project (Liker and Lamb, 2002). A circuit breaker repair process was identified for intervention. Upon enactment of the lean policies, including a “5S” program, a number of positive results were obtained.

The “5S” system was developed in Japan as an outgrowth of the Total Quality movement, where attention is placed on the state of the workplace itself. The name “5S” comes from the Japanese key words associated with the components. Table 4 lists the original Japanese word, the direct translation, and an English-equivalent “S” key word (DiBarra, 2002).

Table 4. “5S” Components

Original Japanese word	Direct translation	English-equivalent “S” word
Seiri	Organization	Sorting
Seiton	Neatness	Simplifying
Seiso	Cleaning	Systematic cleaning
Seiketzu	Standardization	Standardizing
Shitsuke	Discipline	Sustaining

“Sorting” stands for separating what is essential and required to conduct a particular job task from what is not needed. This will reduce workplace clutter and reduce the possibility of hazards from contact with extraneous material (trips, struck by accidents, etc.), “Simplifying” means that all items needed for the immediate work task are stored in particular and unique locations near the work area for ease of retrieval and minimal downtime. “Systematic cleaning” means that the work place is neat and clean. Once normal operating conditions are established, any abnormal conditions are more easily recognized and acted upon, such as the need for preventive maintenance. “Standardizing” stands for the development of common work practices and consistency in how items are stored, how production processes are executed, and how changes are implemented in the workplace. “Sustaining” means the maintenance of gains and the constant improvement on those gains.

Broken test equipment, a shock hazard, and general clutter was removed from the work area. The “5S” program identified 80 non-essential items in the workplace which were removed. The walking distance of the mechanics was reduced by 81%. The lead time to repair the circuit breakers was reduced by over 90%. The floor space utilization improved by 20% and the part travel distance was reduced by 20%.

New Equipment Purchases – The shipyard was recently able to purchase new power tools under a hazard abatement program. New models purchased include the Ingersoll-Rand Cyclone Series pneumatic grinders and sanders, Ingersoll-Rand Series 7 pneumatic drills, the Cleco pneumatic reciprocating saws mentioned earlier, and Honsa tools. New motors for the Aro pneumatic 3” angle grinders vibrated less than the old motors (3-6m/s^2 v. 6-8 m/s^2).

Task Specific Stretching Exercises -- Over the past five years or so, the shipyard has developed a number of task specific stretching exercises that the workers may voluntarily perform prior to carrying out specific operations such as confined space overhead grinding. This reflection of the “industrial athlete” concept is gaining popularity in a number of shipyards.

V. CONCLUSIONS

Five distinct work processes within a ship dismantling operation were surveyed to determine the presence of risk factors associated with musculoskeletal disorders. Possible interventions were previously discussed at length. The scrap sorting operation did participate in a full ergonomic intervention by the addition of a tilting table on the drydock sorting platform. This intervention was deemed successful and additional tables have been purchased by the shipyard.

It is suggested that further action can be taken to mitigate the exposure to musculoskeletal risk factors within each of the identified tasks. The implementation of ergonomic interventions has been found to reduce the amount and severity of musculoskeletal disorders within the working population in various industries.

The interventions proposed in this document are to be considered preliminary concepts. Full engineering analyses by the participating shipyard are expected prior to the implementation of any particular suggested intervention concept to determine feasibility, both financially and engineering, as well as to identify potential safety considerations.

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